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Dynamic Analysis of Regional R and D Efficiency in China Based on DEA and SFA Approaches

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Abstract: This study measures the regional R and D efficiency in China using the panel data from 2002-2011. The results show that the R and D efficiency in China is improved but overall level is not high and the eastern part is higher than the central and western. The mean efficiency calculated by DEA and SFA is on remarkable difference but the correlation is upto 68.1% and the correlation coefficient is upto 0.611 in rank ordering. It is helpful to grasp the dynamic of the R and D efficiency based on panel data and this study, using the two approaches together, can improve the reliability and stability of the result, so that provides reliable basis for the R and D resources allocation.

Key words: R and D efficiency, data envelopment analysis, stochastic frontier

INTRODUCTION

With the accelerating pace of building China into an innovative country, the investments in the Research and Development (R and D) of the whole society further increase. Figures show that the internal spending of R and D expenditures was 128.7 billion Yuan in 2002, accounting for 1.07% of GDP while it increased to 868.7 billion Yuan in 2011, accounting for 1.84% of GDP. National Guideline on Medium- and Long-Term Program for Science and Technology Development (2006-2020) puts forward that the goal of the investment level of R and D expenditures is 2.5%. Faced with the status of increasing R and D expenditures, the academia and all levels of government have focused on the issue of R and D efficiency.

The current methods about the measurement of R and D efficiency are mainly divided into parametric and non-parametric methods. Stochastic Frontier Analysis (SFA) can be the representative of parametric methods. Yuan and Geng (2010) and Zhao (2011) and other scholars have used this method to measure the R and D efficiency in different regions in China. Data Envelopment Analysis (DEA) stands for non-parametric methods (Murillo-Zamorano *et al*., 2001). Wu and Liu (2007) have used this method to measure China R and D efficiency. Panayides *et al*. (2009) reviewed the use of DEA in assessing the seaport efficiency. After comparing, it shows that the method of SFA defines the form of frontier production function but considers the measurement errors and statistical noise (Hjalmarsson *et al*., 1996) while, the method of DEA calculates through linear programming, avoiding the misspecification problem of production function but ignoring the presence of the measurement error and statistical noise. The principles of the two methods are different with their virtues and faults. The credibility of evaluation can be improved by using these two methods simultaneously. Scholars have compared the two different methodologies in a number of other economic sectors (Wang *et al*., 2007; Odeck and Brathen, 2012; Ferrier and Lovell, 1990).

Some scholars have used both methods for the evaluation of R and D efficiency in China but used only the cross-sectional data to conduct static analysis. However, the study is based on the analysis of 30 regional panel data of China from 2002-2011 which is not only in favor of grasping dynamic trends of China's overall R and D efficiency but also provides a more scientific basis for R and D resources allocation.

VARIABLE SELECTION AND MODEL SET

Variable selection

Output variable: Patents, as an important output of R and D activities, have a certain correlation with R and D input (Fabry *et al*., 2006). Patent acceptance and licensing are the important statistical indicators of evaluating regional innovation achievements. The difference between the two indicators is that the number of patent acceptance only reflect the intensity of the research and development of a region while, the number of patent licensing which are qualified after review, directly reflect the ability of research and development production of a region which is one of the important indicators of measuring technological innovation level. Therefore, this study selects the number of patent licensing as output variables.

Input variable: R and D personnel full-time equivalent and R and D spending are generally selected to characterize input variables of R and D activities in literature (Yu, 2014). R and D personnel full-time equivalent can be obtained directly but the spending of R and D expenditures which reflects the actual input of research and development capital of execution unit within the year is a flow indicator (Li *et al*., 2011) and has a lag influence on innovation. Therefore, this study uses the R and D capital stock to characterize the spending of R and D expenditures and the perpetual inventory method to account the R and D capital stock (Griliches, 1991) as described in Eq. 1:

$$K_{it} = E_{i(t-1)}+(1-\delta)K_{i(t-1)} \quad (1)$$

where, K_{it} is the tth year's capital stock, $E_{i(t-1)}$ is expenditures input discounted in the (t-1)th year in region i.

Base capital stock is described as follows:

$$K_{i0} = \frac{E_{i0}}{g+\delta}$$

where, E_{i0} is the input of research and development of base area, g is replaced with average annual growth rate of expenditures, δ is the depreciation rate. Using the general settings in literature, $\delta = 15\%$ (Seema and Thomas, 2008; Wu, 2008). This study takes the year of 2002 as the base and the spending of each province's research and development expenditures from 2002-2011 has deflated to constant R and D spending before measuring the R and D efficiency.

Model set: DEA model mainly concludes Variable Returns to Scale (VRS) and Constant Returns to Scale (CRS). Owning to the influent factors such as the location, resource endowment and the economic environment in each region of China, R and D activity is difficult to keep the best state of the production scale. So, this study select VRS model for its mature and accordingly ignored here (Banker *et al*., 1984).

The method of SFA first chooses the production function. For the reason that this study utilizes panel data and whether the technology and the output elasticity are neutral over time is difficult to determine in advance, use the stochastic frontier model of Transcendental Logarithmic Production Function (Battese and Coelli, 1995) model setting method:

$$\ln Y_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + 1/2\beta_3(\ln K_{it})^2 + 1/2\beta_4(\ln L_{it})^2 + \beta_5 \ln K_{it} \ln L_{it} + V_{it} - U_{it}$$

where, Y_{it}, K_{it} and L_{it} are the number of patent licensing in tth year in region i, R and D capital stock and R and D personnel full-time equivalent, respectively, V_{it} is the item of random error related to the statistical noise.

Suppose, V_{it}~$N(0, \sigma^2_v)$; U_{it} is on behalf of the item that the management is invalid and obey the nonnegative tail normal distribution, namely U_{it}~$N^+(u, \sigma^2_u)$. Battese and Coelli (1995) designed γ, the parameter of variance:

$$\gamma = \frac{\sigma^2_u}{\sigma^2_v + \sigma^2_u}$$

to test the technical inefficiency's proportion in the disturbance term:

$$0 \le \gamma \le 1$$

Obtain its value by maximum likelihood estimation. When γ is 0, it illustrates that the gap between actual output and frontier production mainly comes from the random error. At the moment, use the least squares estimation without the need to use SFA technique.

Data sources: In this study, the original data is from China statistical yearbook and China statistical yearbook of science and technology. Take R and D input and output data from 2002-2011 in 30 regions in China as sample. Due to the more missing data of Tibet and thus eliminate it, eventually receive 300 data from 10 years in 30 provinces and cities of China. In addition, according to the division of the middle East, the central and the West in the annals, the East includes, Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan. The middle includes Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan. The West includes, Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang.

EMPIRICAL ANALYZING

Use DEAP2.1 and FRONTIER4.1 to calculate the empirical results of the two methods, respectively. Table 1 lists the measured results of the model

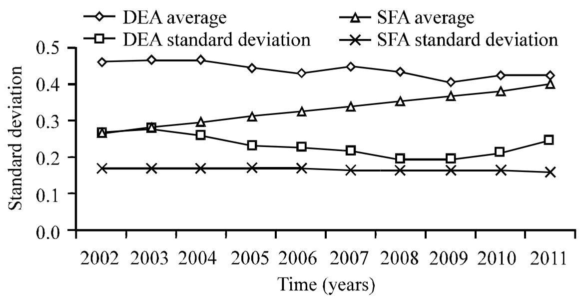

Fig. 1: Time trend of average and standard deviation of the results from two methods

Table 1: Estimation results of stochastic frontier production function

Estimated parameters	Coefficient	t-value
β_0	14.8236***	6.1476
β_1	-2.4189***	-5.2917
β_2	1.0920**	2.0535
β_3	0.3119***	5.6527
β_4	0.1231	1.0904
β_5	-0.1394*	-1.9588
σ^2	0.2662***	5.5456
γ	0.8355***	44.2138
μ	0.9432***	6.5845
η	0.0447***	6.1348

***,**,*Mean notable at 1, 5 and 10% levels, respectively with double tail inspection

Table 2: Descriptive statistics of empirical results

Method	Sample size	Mean of the efficiency	Standard deviation	Maximum value	Minimum value
DEA	300	0.441	0.231	1	0.096
SFA	300	0.333	0.169	0.929	0.051

of Transcendental Logarithmic Production Function. And γ is remarkable under the level of 1% which shows that the panel data is fit for the method of SFA. When γ is 0.8355, it indicates that management inefficiency accounts for 83.55%. Table 2 shows the descriptive statistics of the results from two methods. From the point of average efficiency, the overall R and D efficiency in 30 provinces in China is low and the measuring results of DEA method are higher than that of SFA, with only 0.441. Considering standard deviation, the results of DEA are higher than that of SFA which illustrates that the discrete degree of SFA distribution is small and the results of evaluation are more stable. Figure 1 shows the average and standard deviation's dynamic trend with time during the investigation period. The figure shows the measuring results of DEA have a big fluctuation and the results of SFA continue to rise which illustrates that China overall R and D efficiency tends to rise during the investigation period.

Table 3 list the average efficiency of the two estimation results in 30 Chinese provinces during the probation period and rank. From the point of regional distribution, the average R and D efficiency of the two kinds of methods shows that the average R and D efficiency from eastern region is significantly higher than that of the other two regions which is consistent with the results of the study of Zhang (2014) and Zhang *et al.* (2012). The results from using the paired T to test probation show that the correlation coefficient of the average efficiency between DEA and SFA is 0.681 and the value of p is 0 which illustrates that there exists a strong correlation between the calculation results of two methods. In the 95% confidence interval, the testing value of paired T is 3.681 and the significant probability is 0.001 which illustrates that the measuring mean of the efficiency of the two kinds of methods has a significant difference. In addition, the provinces which have a significant difference in the results of the two kinds of methods are Fujian, Guangdong, Hainan, Inner Mongolia, Ningxia and Xinjiang. On the one hand, the DEA is focused on the relative efficiency evaluation of each province which leads to the relatively higher result. On the other hand, SFA considers random factors' influence on the efficiency. Lower results show that there is larger statistical noise in these provinces R and D efficiency.

Table 3: Average and rank of the measuring results from Chinese regions

Area and DEA average	Rank	SFA average	Rank	Area
East				
Beijing	0.211	26	0.133	29
Tianjin	0.288	22	0.298	18
Hebei	0.418	16	0.328	12
Liaoning	0.268	23	0.283	19
Shanghai	0.466	11	0.406	6
Jiangsu	0.320	19	0.412	5
Zhejiang	1.000	1	0.914	1
Fujian	0.839	5	0.549	4
Shandong	0.407	17	0.395	8
Guangdong	0.999	2	0.633	2
Hainan	0.895	3	0.250	22
Average	0.556		0.418	
Central				
Shanxi	0.302	20	0.217	25
Jilin	0.294	21	0.240	24
Heilongjiang	0.368	18	0.300	17
Anhui	0.260	24	0.301	16
Jiangxi	0.419	15	0.251	21
Henan	0.427	14	0.359	10
Hubei	0.203	27	0.268	20
Hunan	0.433	12	0.405	7
Average	0.338		0.292	
West				
Inner Mongolia	0.838	6	0.241	23
Guangxi	0.566	8	0.307	15
Chongqing	0.700	7	0.567	3
Sichuang	0.213	25	0.323	14
Guizhou	0.431	13	0.327	13
Yunnan	0.488	10	0.332	11
Shanxi	0.096	30	0.137	28
Gansu	0.135	29	0.143	27
Qinghai	0.181	28	0.091	30
Ningxia	0.525	9	0.183	26
Xinjiang	0.892	4	0.383	9
Average	0.460		0.276	
National average	0.463		0.333	

From the point of order, there are always 4 provinces and cities from eastern regions in the top five in the two kinds of measuring results and three provinces and cities from the western regions in the last five. Use the Spearman rank correlation to test and the results show that the correlation coefficient of the measuring results rank of the two kinds of methods is 0.611 and significant under 1% level which shows that the rank of efficiency value between SFA and DEA is consistent. This coincides with the conclusion that the ranks in the two kinds of methods are consistent with the study of Wu and Liu (2007).

From Table 3, it can be seen that the R and D efficiency in the other provinces and cities such as Beijing, Tianjin and Liaoning is lower and lower rank while Yunnan, Xinjiang and other provinces are relative on high-ranking. Therefore, there is no direct rank between the R and D efficiency level and economic level and geographic position which further verifies the conclusion of Wang (2009).

CONCLUSION AND RECOMMENDATIONS

Based on the methods of DEA and SFA and using the panel data from 2002-2011 to compare with the R and D efficiency of China's 30 provinces and cities, this study comes to the following conclusions:

- China's overall R and D efficiency during the investigation period is lower. From the point of regional distribution, the eastern region is significantly higher than the Midwest. From the point of time dimension, China's overall R and D efficiency has been improved over the past ten years, especially in the central and western regions where have a large room to improve
- The average efficiency measured by the methods of DEA and SFA shows significant differences but the correlation is upto 68.1%. The correlation coefficient of the measuring results from the two methods in the ordering aspect is 0.611 which shows high consistency. Combine these two methods to test the efficiency of R and D which enhances the robustness of the results
- There is no direct link between R and D efficiency intensity and the economic level

According to the above conclusions, this study puts forward the following suggestions: First, continue to enhance investment in research and development. Actively promote the implementation of the goal of 2.5% R and D input intensity of National Guideline on Medium- and Long-Term Program for Science and Technology Development (2006-2020). Optimize the system of multiple expenses input to guide more social capital pouring into the field of scientific and technological innovation. Increase the science and technology plan and the support to the fund of the plan of science and technology to encourage the enterprises, universities and research institutes to carry out the innovation activity. Continue to implement the high-level talents introduction plan to further increase the incentive intensity of creative talents to encourage more talented persons into research and development activities. Second, further optimize the structure of R and D input. Constantly increase investment in basic research to improve Chinese original innovation ability to solve a number of key core technologies in the development of emerging industries, raise the main body status of enterprises in R and D activities, guide technology resources flow into the enterprise and encourage enterprise technology innovation activities. Finally, set up R and D efficiency evaluation system as soon as possible. In view of the actual situation in the eastern, central and western provinces, establish a scientific and reasonable evaluation system of the R and D efficiency to provide a scientific basis for the allocation of R and D resources in the provinces and cities.

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